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Infrared ship target segmentation through integration of multiple feature maps☆

Zhaoying Liu[a,b,d], Xiangzhi Bai[b,c,*], Changming Sun[d], Fugen Zhou[b,c], Yujian Li[a]

[a] College of Computer Science, Beijing University of Technology, Beijing 100124, China
[b] Image Processing Center, Beihang University, Beijing 100191, China
[c] State Key Laboratory of Virtual Reality Technology and Systems, Beihang University, Beijing 100191, China
[d] CSIRO Digital Productivity Flagship, Locked Bag 17, North Ryde, NSW 1670, Australia

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ABSTRACT

We investigate the issue of ship target segmentation in infrared (IR) images, and propose an efficient method based on feature map integration. It consists of mainly two procedures: salient region detection based on multiple feature map integration and salient region segmentation based on locally adaptive thresholding. Firstly, a saliency map is constructed by integrating multiple features of IR ship targets, including gray level intensity, local contrast, salient linear structures, and edge strength. Secondly, we propose an adaptive thresholding method to segment each local salient region, and a target selection procedure based on shape features is used to remove background and obtain the true target. Experimental results show that the proposed method performs well for IR ship target segmentation. The advantage of the proposed method is demonstrated in both visual and quantitative comparisons, especially for IR images with a bright background or a ship target close to port.

1. Introduction

In recent years, infrared (IR) imaging system has been widely used for maritime security, such as harbor surveillance, maritime search and rescue, and ship target tracking [1]. As a crucial step, IR ship target segmentation plays an important role in the above applications. It facilitates the detection of important features for subsequent imaging processing [2,3]. However, as the intensity values of an IR image depend on the temperatures of the imaged target and background, weather and atmospheric conditions, the image quality is sensitive to variations of the imaging scenario [4]. Generally, IR images are characterized by low resolution, low signal-to-noise ratio (SNR), and low target-to-background contrast [5]. Moreover, when the target is close to the background, it is difficult to separate the target from the background. All these challenges make ship target segmentation in IR images a tough task.

Many investigations have been conducted to solve this problem, and many methods have been proposed. For instance, the mean-shift based method, which is a feature-space analysis method, has been applied for image segmentation, clustering and tracking [6]. The mean shift method works well for IR ship target segmentation in a sea background [7]. However, the segmentation process is based on region merging, where some target regions may be eliminated when the size is small, or wrongly merged with the background when the contrast is low. Active-contour based method is also commonly used for image segmentation [8]. The traditional Chan–Vese (C–V) model [9] only works well for images with statistically homogeneous intensities [10]. To overcome this issue, some improved models combining the local and global information were proposed, such as methods in [10,11]. However, the segmentation results of these methods are sensitive to initialization and time consuming. To address these problems, several strategies have been applied to improve the efficiency. For example, to achieve fast auroral oval segmentation, shape knowledge based initialization procedure has been proposed to improve the segmentation accuracy and its convergence rate [12,13]. And to further accelerate the segmentation, a multi strategies method combining universal lattice Boltzmann method (LBM) and sparse field method (SFM) have been developed [13]. Moreover, based on the assumption that the energy function of a pixel is defined by both the pixel and its neighbors, a noise robust Markov random field (MRF) embedded level set model is proposed. And during the implementation of this method, an algebraic multigrid (AMG) and SFM are applied to reduce the computational time [14]. Another commonly used method is based

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* Corresponding author at: Image Processing Center, Beihang University, Beijing 100191, China.
E-mail address: jackybxz@buaa.edu.cn (X. Bai).

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on thresholding [15]. Thresholding is one of the most powerful tools for image segmentation. Classical thresholding methods have the advantages of simplicity and efficiency, such as Otsu's method [16], entropy based method [17], and thresholding based on clustering criteria [18]. However, as these methods only take into account of the intensity information and ignore the spatial information between pixels, they are sensitive to noises. To compensate for this, thresholding methods considering spatial information are introduced, such as the spatial fuzzy C-means [19], 2D Otsu [20], and 2D entropy based methods [21]. These methods are less prone to noise due to the use of spatial information. Nevertheless, their performances are affected by the ratio of pixel numbers on the background and the target regions, and they cannot achieve satisfactory results when the contrast is low or the target is too small.

In our previous work [22], we developed an iterative global thresholding (IGT) method. The IGT method can overcome several existing problems of IR ship target segmentation, such as low contrast, multiple targets, and uneven backgrounds. It has a good performance for IR images with different backgrounds. However, the IGT method assumes that the target region is much brighter than the background, it does not work well for images with bright backgrounds and large ship targets with non-uniform intensities. Moreover, in the region selection procedure, it will take a ship target obtained from front view as background and remove it.

Therefore, despite many methods have been developed, we are still far from solving the problem of IR image segmentation. In recent years, there has been a trend towards algorithms that integrate multiple features [23,24]. As each feature can capture part of the information contained in an image, it is possible to produce better results by taking advantage of complementary properties of various features. And due to the fact that a target can often attract attention in an IR image, saliency based method is becoming important for IR target detection [25] and other image analysis tasks [26]. In this paper, to deal with the problems encountered in [22] and other approaches, we propose an effective IR ship target segmentation method by integrating multiple feature maps. Firstly, we propose a saliency map detection method through multiple feature map integration. In this step, discriminative and robust feature maps are extracted independently, including image intensity, local contrast, salient linear structures, and edge strength. And then all the feature maps are integrated to obtain a saliency map. As a preliminary step, a pre-processing procedure based on fast bilateral filtering is used to remove noises and smooth complex backgrounds. Secondly, an adaptive thresholding method is developed to segment each local salient region, and a target selection procedure is applied to obtain the true ship target. Experimental results demonstrate that our method can achieve good segmentation results for IR images with low and high contrasts, and it can segment ship targets with different sizes. Comparison results indicate that our method achieves a better performance for both visual and quantitative evaluations, especially for IR images with bright backgrounds and ship targets closely connected with the background.

2. Algorithms

The flowchart of the proposed method is shown in Fig. 1 Details are given in the following sections.

2.1. Salient region detection based on feature map integration

The IR images are obtained from different maritime environments, and some samples are shown in Fig. 2 These images have different types of backgrounds and different contrasts, and the sizes of the ship targets vary considerably. So it is difficult to segment all the images using only one or two simple features. To achieve an effective segmentation, feature integration is an applicable approach. By combining multiple features, we can have more information of the target from different imaging angles [27]. Based on observations on these images, we can find that they have some common characteristics. For instance, the ship target is a connected region with a regular shape, and it appears as a bright salient region with a fuzzy contour comparing with its surrounding background; and the local contrast around the target region is much higher. Although for some images the ship target is connected with a port (e.g., the first and the second images in the first row of Fig. 2 , boundary of the port can be used to separate them. Therefore, we propose a feature map integration method for effective segmentation. By integrating complementary information of various features, we intend to highlight the target regions as well as to separate the target regions from the background.

2.1.1. Image pre-processing based on fast bilateral filtering

IR images usually have high noise levels, and complex background will increase the difficulty of image segmentation. Therefore, effective pre-processing is necessary to improve the IR image quality. Various image pre-processing algorithms have been proposed to remove noises or enhance useful details and contrast [28]. Among the existing methods, bilateral filtering allows one to perform smoothing while preserving edges at the same time [29]. This filter has found widespread use in various image processing and computer vision applications. In this paper, we use the fast bilateral filtering method proposed in [30], which implements the bilateral filter in constant time using trigonometric range kernels. As shown in Fig. 3 (b), after the fast bilateral filtering, the background is effectively smooth, while the details of the ship target are well preserved. This is beneficial for the following ship target segmentation.

2.1.2. Local row contrast map detection

From Fig. 2 we can see that there are mainly three regions in the IR ship target images. These regions are sky or land background, ship target, and sea background. The intensity distributions vary according to each row. For the sky and sea background regions, their local contrasts are low; while for the ship target region, the local contrast is high. Therefore, local contrast can be used to distinguish the ship target from the background regions. To obtain the local contrast map, we use a block-based representation inspired by the work in [31]. Given an IR image I with size $S_r \times S_c$, the filtered image is denoted as I_f. First we divide the image I_f into $M \times N$ non-overlapping blocks $\{P_{11}, \dots, P_{1N}; \dots; P_{i1}, \dots, P_{iN}; P_{M1}, \dots, P_{MN}\}$ with P_{ij} being a $w \times w$ image block, $1 \leq i \leq M$; $1 \leq j \leq N$. In the implementation, we set $w = 5$. The local row contrast measures the distinction between a given patch P_{ij} and an averaged patch from row i of the blocked image, defined as

$$I_{lrc}(P_{ij}) = \text{sign}(P_{ij} - mRow_i) \cdot \|P_{ij} - mRow_i\|_2 \quad (1)$$

where sign(x) is a sign function with sign(x) $= -1$, if $x < 0$; sign(x) $= 1$, if $x > 0$; and sign(x) $= 0$, otherwise. $\| \cdot \|_2$ represents the l_2 norm; $mRow_i$ is the averaged patch of row i of the blocked image, i.e., $mRow_i = 1/N \sum_{j=1}^{N} P_{ij}$. This local row contrast map can represent the local saliency of the ship target region, as shown in Fig. 3 (c).

2.1.3. Edge strength map detection

A ship target region appears as a closed connected region with fuzzy contours, including important edge features. Therefore, we use edge strength as another feature to highlight the ship target region. To detect the edge strength map, a scale multiplication method is used as in [32]. Two detection filters in x and y directions are used, denoted as $f_s^x(x,y)$ and $f_s^y(x,y)$, respectively. Here, s is the scale. Their responses to image I_f are $H_x^s(x,y)$ and $H_y^s(x,y)$, respectively. Two scales